Legume production and irrigation strategies in the Aral sea basin: yield, yield components and water relations of common bean (Phaseolus Vulgaris) and green gram (Vigna Radiata (L.) Wilczek)

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LEGUME PRODUCTION AND IRRIGATION STRATEGIES IN THE ARAL SEA BASIN:YIELD, YIELD COMPONENTS AND WATER RELATIONS OF COMMON BEAN (PHASEOLUS VULGARIS) AND GREEN GRAM (VIGNA RADIATA (L.) WILCZEK)

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SUMMARY - In the Aral Sea basin, limited water resources, environmental damage and extensive production of cotton have lead to a need for more efficient irrigation strategies and the production of crops that could aid in food self sufficiency. Improved irrigation methods are needed, to increase the productivity of agricultural land and improve food supply. The objective of this work was to examine the effect of irrigation strategies on the yield and yield components of two legume species, produced after the harvest of winter wheat. Water relations were also examined. The research was conducted during two successive growing seasons in the Fergana Valley of Uzbekistan. The experiment was organized following a randomized complete block split-plot design with four blocks. The treatments were comprised of factorial combinations of three factors: regulated deficit irrigation level (recommended level, moderate deficit and severe deficit), irrigation water distribution pattern (alternate and every furrow irrigation) and crop [bean (*Phaseolus vulgaris*) and green gram (*Vigna radiata* (L.) Wilczek)]. Regulated deficit irrigation decreased yields of common bean, but increased yields of green gram. Alternate furrow irrigation did not reduce yields and, in general, green gram yields were higher than those of common bean. The combination of alternate furrow and deficit irrigation can allow legume production with reduced water inputs. A winter wheat-legume rotation appears feasible in Uzbekistan and provides a more food self-sufficient alternative that can be integrated the current cotton-winter wheat cropping system.

Key words : Common bean (*Phaseolus vulgaris*), Green Gram (*Vigna radiata* (L.) Wilczek), regulated deficit irrigation, alternate furrow irrigation

RESUME- *Dans le bassin de la mer Aral, les ressources hydriques limitées, les dommages environnementaux et la production extensive de coton ont menés à un besoin criant pour des stratégies d'irrigation plus efficaces et pour une production agricole aidant à l'autosuffisance agro-alimentaire. De meilleures stratégies d'irrigation sont nécessaires pour augmenter la productivité des terres agricoles et les réserves alimentaires. L'objectif de cette étude était d'examiner les effets de stratégies d'irrigation sur le rendement et ses composés de deux cultures de légumineuses, produites après la récolte de blé d'hiver. Les relations hydriques ont aussi été examinées. Cette recherche a été effectuée pendant deux saisons de croissance consécutives dans la vallée de Fergana, en Ouzbékistan. L'expérience a été organisée suivant une conception expérimentale à bloc complet randomisé et split-plot, avec quatre blocs. Les traitements étaient des combinaisons factorielles de trois facteurs : le niveau d'irrigation déficitaire (recommandé, stress modéré ou stress sévère), la distribution (irrigation alternante ou irrigation conventionnelle), et la culture [haricot commun (*Phaseolus vulagris*) ou haricot mung (*Vigna radiata* (L.) Wilczek)]. L'irrigation déficitaire a diminué les rendements du haricot commun, mais a augmenté les rendements du haricot mung. L'irrigation alternante n'a pas diminué les rendements, et en général, les rendements du haricot mung étaient supérieurs aux rendements du haricot commun. La production de légumineuses avec une faible contribution en eau est possible avec la combinaison de l'irrigation déficitaire et alternante. Une* *rotation de blé d'hiver-légumineuse semble possible en Ouzbékistan et apporterait une alternative agro-alimentaire qui s'intègre bien à la rotation coton-blé qui prévaut présentement.*

***Mots-clés** : Haricot commun (*Phaseolus vulgaris*), haricot mung (Vigna* radiata *(L.) Wilczek), irrigation déficitaire, irrigation alternante*

INTRODUCTION

The problem of water availability for food production has had, and will continue to have, environmental and social costs. Perhaps the most extreme example of these at this time is the drying of the Aral Sea. Land and water resources have been degraded due to the expansion of irrigation networks and on-farm mismanagement of irrigation water, and have caused serious health problems in the lower reaches of the two large rivers flowing into the Aral Sea (Micklin, 2000; Dukhovny, 2005).

Regulated deficit irrigation (RDI) consists of finding the optimum balance between water use and crop yield. Under RDI, crop producers allow the crop to experience some water stress, but the water saved should allow an increase in the area irrigated, or it could be put to more productive use. ICARDA has shown that a 50% reduction in irrigation water applied decreased yields by 10 to 15%, and overall farm productivity increased by 38% when the water saved was used on other land (Pereira et al. 2002).

Previous studies on RDI were usually performed by reducing the amount of water that is applied to crops. While this might be practical with sprinkler and drip irrigation, in developing countries where furrow irrigation is most widely used, very small irrigation depths are not technically feasible. The authors feel that RDI using increased time intervals between irrigation events, based on the water balance method for irrigation scheduling (as used in this study), is a better approach because: (i) it is available no matter what water application technology (or lack thereof) is being used, (ii) the water stress is reproducible over soil types and climatic conditions, and (iii) crop producers can easily adapt their irrigation scheduling tools to implement RDI. No clear guidelines for irrigation are given when studies compare various levels of irrigation, or when RDI is set at a certain percentage of the evapotranspiration. Unfortunately, there is very little literature regarding practical RDI application.

Alternate furrow irrigation utilizes surface irrigation systems that supply water to every second furrow, instead of to every furrow. Kang et al. (1998) have shown that, by alternating irrigated furrows, root growth was stimulated and this probably helps offset negative effects of reduced water supply. They showed that water consumption was decreased by 34.4 to 36.8% while yields only decreased 6 to 11%. They suggested that by having half of its roots in dry soil, the plant continues to synthesize moisture deficit related ABA in the roots, which leads to reduced transpiration rates.

Common bean is a very diverse large-seeded pulse crop, with approximately 500 varieties. The genus *Phaseolus* originated from the Neotropics (Brougthon et al., 2003), and there is evidence of bean domestication in the Peruvian Andes by about 4400 BC, and by about 2500 BC in Mexico at the earliest (Kaplan and Lynch, 1999). It is the most important legume crop in the world, being eaten directly by humans more than any other. The estimated value of its 18-million-ton annual harvest is approximately US$11 billion (CIAT, 2001). A recent study also suggests that only 7% of the common bean cultivated area receives adequate rainfall (Broughton et al., 2003).

Green gram, also known as mungbean, is a small-seeded crop less known in the Americas, but widely cultivated in Asia (India, Pakistan, Bangladesh, Thailand, Malaysia, the Philippines) (Hafeez *et al*., 1991; Hanelt and IPK, 2001). It is also cultivated to some degree in the United States and in Australia, often as a green manure and/or for sprouting. Green gram has approximately 40 varieties, mostly of Indian origin, where it has been cultivated since at least 3500 BC (Hanelt and IPK, 2001). In Uzbekistan, the crop is known as one that performs well under conditions of low soil moisture. It remains however one of the least researched and most under-exploited legume crops (DeCosta et al., 1999). Green gram was once classified in the genus *Phaseolus*, as *P. aureus*, but it has been moved to the genus *Vigna*, a group that is generally regarded as drought tolerant. In addition, while rhizobial symbionts of common bean cannot nodulate green gram, the rhizobia of the cowpea miscellany can. Unfortunately, *P. aureus* is still used occasionally in Central Asia (for example Provorov *et al*., 1998).

The data available for the economic productivity of green gram shows that the culture can be profitable, particularly when compared to other vegetables or grains (SIC ICWC, 1997).

Agricultural policies in Uzbekistan emphasize the culture of cotton, an important component of the Uzbek economy, and to a lesser degree, winter wheat. Both are subject to state regulation through a system of quotas, and little agricultural land is left for other food crops (M. Souleimenov, pers. Comm..). The objective of this work was to evaluate the production of food legumes seeded after the harvest of winter wheat (early July). Being short-seasoned, legumes can be grown in this time period, and they represent a good source of protein for human consumption. Bean and green gram have been chosen because they are grown and consumed in Central Asia, including Uzbekistan. This study is the first to evaluate the effect of regulated deficit irrigation using the water balance method (i.e increased time intervals between irrigation events) in conjunction with alternate furrow irrigation on the yield of common bean and green gram (see also Webber *et al.*, 2006).

MATERIALS AND METHODS

Environment

The experiment was conducted in the Fergana Valley, in Uzbekistan, Central Asia (40°23'N, 71°45'W) from the beginning of July until the onset of cold temperatures in mid-October, in the growing seasons of 2003 and 2004. During this period, the climate is hot and dry, with typical daily high temperatures being 40 °C, and daily lows being 20 °C. Rain is very infrequent, except in early October. From July 15th to September 30th 2003 and 2004, we recorded a total of 8.8 and 7.6 mm of rainfall, respectively, at our field sites. Climatic data was collected using an on-site Vantage Pro Meteorological station (Davis Instruments Corp., Hayward, USA), approximately 200 m from the field site. The soil at the experimental sites was a silt loam in 2003 and ranged from a sandy loam to a silt loam in 2004. In both years, the soils had low organic matter contents (less than 1%), and a well developed plow pan at 30-40 cm.

Design

The treatments were organized on the field site following a randomized complete block split-plot design. The treatments were comprised of factorial combinations of three factors: regulated deficit irrigation level (recommended level, moderate deficit and severe deficit), irrigation water distribution pattern (alternate and every furrow irrigation) and crop (common bean and green gram). Regulated deficit irrigation treatment was the main plot factor and the combinations of furrow irrigation strategy and crop constituted the subplot factor. There were four blocks. Each subplot measured 15 x 12 meters with an additional 1.5 meter of buffer zone on each side of the irrigation ditch.

Levels of deficit irrigation were determined according to the concept of soil water depletion fractions, as defined by the FAO Water Report #56 (Table 22, Allen *et al*., 1998). Depletion fractions are measures of soil water depletion as a percentage of the available soil water; the longer the interval of time between irrigation events the higher the depletion fraction. For bean, the depletion fractions used were 0.45 as the recommended level (Allen *et al.*, 1998), 0.6 and 0.7 as the moderate and severe stress levels, respectively. For green gram, the recommended depletion fraction was also 0.45 (Allen *et al.*, 1998), but the moderate and severe stress levels were 0.65 and 0.8. Local producers informed us that only one irrigation event is necessary for this crop, suggesting greater tolerance to water stress than most, and this is why we used greater depletion fractions for green gram. In addition, we believed that these depletion fractions would be good estimators of a moderate and a severe level of stress for the two crops. At this time there is no information available regarding regulated deficit irrigation depletion fractions for bean or green gram.

Irrigation scheduling was based on the water balance method, and climatic data from our meteorological stations, soil moisture readings, and an evapotranspiration gauge placed in a green gram plot adjacent to our experimental field. Details of the irrigation scheduling method are described in Webber *et al.* (2006). Soil water content was determined by the gravimetric method for depths of 0, 10 and 20 cm, and with a neutron probe (Neutron, Moscow, Russia) for depths of 40 and 60 cm.

For alternate furrow irrigation, the head of every other furrow was blocked. Blocked furrows were alternated between irrigation events, when there was more than one event.

Cultural practices

The field sites produced winter wheat immediately prior to our experimentation. The wheat had been harvested, the straw and stubble burned, the field plowed and leveled, all following standard practices in the region. Sixty-cm wide furrows were formed on the field site with a tractor drawn lister; a pre-irrigation was applied to consolidate the resulting furrows and raised beds.

Seeds for the crops were purchased at a local market, and harvested seeds were kept for planting in the second year. We have retained a sample of these seeds and they are available, upon request. Seeds were sown on both sides of the raised beds, at 10 cm intervals, to achieve a plant density of 300,000 plants ha^{-1}. Planting was done on July 14 and 15th in 2003, and July 9-12th in 2004. In 2004, based on experience acquired in 2003, an irrigation event was included at five days after seeding, to assist in seedling establishment. Fertilization in 2003 consisted in 115 kg ha^{-1} of superphosphate, applied immediately prior to the land leveling, plus a manual application of ammonium phosphate (100 kg ha^{-1}) and potassium (15 kg ha^{-1}) a week after planting. In 2004, a mix of phosphate and potassium was applied at a rate of 150 kg ha^{-1} and 75 kg ha^{-1}, respectively, during the pre-irrigation. Weed control was done manually. On one or two occasions in 2003 and 2004 respectively, an insecticide was applied to the crop, following local recommendations.

Multiple harvests were necessary as green gram pods tended to shatter when dry. In 2003, there were two harvests for bean (October 3rd and 14th), and six for green gram (September 21st, 24th, 27th, 30th, October 7th and 13th, 2003). In 2004, there were also two harvests for bean (September 20th, and October 3rd), and four for green gram (September 21st, 26th, October 1st and 9th).

Measurements

An area of 5 x 5 m, in the center of each plot, was used for sampling. Mature pods were harvested in the sampling area at regular intervals and threshed by hand. Grain yield was determined for each harvest, then combined for analysis and later corrected for moisture content. One hundred seeds were randomly selected from those harvested from each plot and these were used to determine 100-seed weight; this subset was then oven-dried at 65-70 °C for 24 h (or more when needed) to determine seed moisture level. Number of seeds per pod was also determined at each harvest, from 10 pods randomly picked within the sampling area of each subplot. Pods per plant were counted on six randomly selected plants within the sampling area at the first harvest. Harvest index was calculated as the ratio of yield over total above-ground biomass at final harvest. Biomass was determined by harvesting 0.5 m of row and drying it at 70 ˚C for at least 24 h, or until dry (at constant weight). Stem water potential was measured on six plants per plot within the sampling area, one day before and two days after irrigation events with a portable pump-up pressure bomb (PMS Instruments, Albany, USA). Stomatal conductance was measured from ten plants at the same time as stem water potential, with a diffusion porometer LICOR-1600M (Li-Cor, Lincoln, Nebraska USA).

Statistical analysis

Statistical analyses were performed by analysis of variance (ANOVA) using the SAS/STAT software (SAS, Cary, USA). In general, differences among treatments were considered significant only when they occurred at the 0.05 level of probability. However, in some cases relevant differences are discussed when the probability level is between 0.05 and 0.1; in these cases, the p value is given in the text. Means separations were performed using the t-tests on least square means In 2003, when significant, the population density was used as a covariant.

RESULTS

Yield

Green gram responded differently than common bean to the various levels of water stress imposed during this experiment (Fig. 1) with p values of $P \leq 0.0913$ and $P \leq 0.0005$ for 2003 and 2004 respectively.

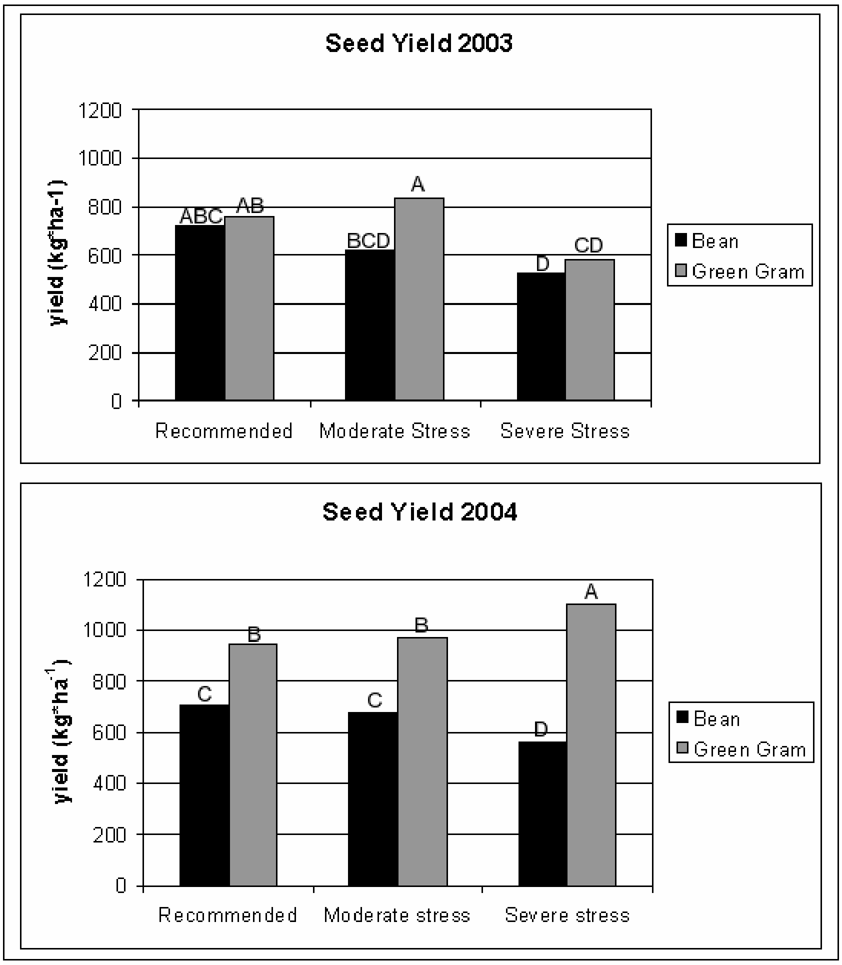

Fig. 1. Common bean and green gram yields in 2003 and 2004 under three levels of water stress in the Fergana Valley, Uzbekistan. Histogram bars associated with the same letter are not different ($P \leq 0.05$) within the same year by t-tests on least-square means. (Note : the crop by depletion fraction interaction was significant at $P \leq 0.0913$ in 2003, while in 2004 this interaction was significant at $P \leq 0.0005$)

While bean yields decreased with increasing stress, green gram showed the highest yields in the moderate water stress level (2003) and severe stress level (2004). Interestingly, bean yields in the moderate stress level were only slightly lower than bean yields in the recommended irrigation schedule, and not significantly so. In addition, alternate furrow irrigation did not reduce yields. The yield difference between the two experimental years can probably be explained in part by the differences in the population density. In 2003, variation was relatively high, due to uneven emergence. In particular, in the severe stress treatment, the population density of green gram was below optimal, reaching only 50% ground cover, which probably led to different, more stressful, environmental conditions for these plants, contributing to lower yields.

Number of seeds per pod

The number of seeds per pod was higher for green gram than for bean, with averages around 10 and 3, respectively which was expected given the nature of the crops. More inte-restingly, the number of seeds per pod decreased differently between green gram and common bean (*Table 1*). While the number of seeds decreased with increasing water stress for both crops, this decrease was sharp in green gram in the severe stress treatment. This crop by depletion fraction interaction was not as significant in 2003 as in 2004 (p values of 0.0585 and 0.0024 respectively). There was also a weak significant difference ($\leq$ 0.0441) between alternate and every furrow irrigation strategies which only occurred in 2004. Since yields were not affected by alternate furrow irrigation, it is unclear whether this irrigation strategy really has a negative impact on the number of seeds per pod.

Seed weight

Seeds of green gram are much smaller than those of bean: 5 to 6 g per 100 seeds compared to 35-43 g, respectively. Seed weight seemed not to be affected by depletion fractions (*Table 1*) or furrow irrigation strategies. In addition, there was no crop by depletion fraction interaction, or any other significant interaction in either year. Interestingly, seeds were smaller in 2004 than 2003 for both crops. Nitrogen content in the 2004 field was less than in the field used in 2003 (data not shown). In addition, the higher plant density in 2004 might have led to greater competition among plants, and lower seed weights.

Pods per plant

Again, there was a strong crop by depletion fraction interaction in both years for the number of pods per plant (*Table 1*). For green gram, the number of pods per plant decreased sharply in the severe stress treatment, as compared to the moderate stress and recommended levels. In contrast, bean had a slight, but non-significant increase in the number of pods per plant with increasing water stress. The difference in the number of pods per plant between the two years could probably be partially explained by the lower nitrogen level of the field (and lack of availability of nitrogen fertilizer) in 2004. Also, the population density was relatively low for green gram in 2003. As such, it seems that green gram in the recommended and moderate stress irrigation schedule treatments had enough water to compensate for the low density by growing to their full potential, thus explaining large numbers of pods per plant in 2003.

Table 1. Yield components of common bean and green gram under various levels of regulated deficit irrigation and alternate furrow irrigation

		Number of Seeds per Pod		100-seed weight (g)		Number of Pods per Plant	
Crop	Depletion fraction	2003	2004	2003	2004	2003	2004
Bean	Recommended	3.7 c*	3.3 c	41.4 b	34.6 a	11.7 c	5.0 c
	Moderate stress	3.2 c	3.1 c	42.4 ab	33.6 a	13.1 c	4.4 c
	Severe stress	3.3 c	2.9 c	44.0 a	34.2 a	16.0 c	5.1 c
Green Gram	Recommended	11.1 a	10.8 a	5.5 c	5.2 b	47.9 a	16.5 a
	Moderate stress	10.6 ab	10.5 a	5.8 c	4.8 b	45.0 a	15.3 ab
	Severe stress	10.1 b	9.5 b	6.2 c	5.0 b	27.0 b	13.3 b
Interaction significance		$P \leq 0.0585$	$P \leq 0.0024$	$P \leq 0.1255$	$P \leq 0.8788$	$P < 0.0001$	$P \leq 0.0099$

* Values with the same letter do not differ significantly

Harvest index

Harvest index (HI) was affected by deficit irrigation at harvest but differently for the two crops in both years. Common bean seems to decrease its HI with increasing stress, while green gram seems to increase HI with increasing stress (data not shown), although there were little differences between the recommended irrigation schedule and the moderate stress depletion level within crops. It seems thus that green gram has a greater capacity than common bean to allocate resources to seeds under conditions of severe stress.

Stem Water Potential

Before Irrigation Events

In both years, green gram maintained a higher (i.e. less negative) stem water potential (SWP) than common bean across depletion fractions and furrow strategies. In addition, the SWP was not different between furrow irrigation strategies in either year. The data for SWP unfortunately, shows different responses to depletion fractions for each year (*Table 2*). In 2003, there was a strongly significant crop by depletion fraction interaction in which green gram decreased its SWP potential with increasing stress, while common bean showed the lowest SWP at the moderate stress level. This might lead one to think that bean has a capacity to osmotically adjust but only until a threshold of water stress. This interaction however was not significant in 2004 ($P<0.1238$), and numerically, the lowest SWP in bean was in the severe stress level, whereas for green gram, all depletion levels showed the same SWP. These conflicting results makes it difficult to assess the capacity for both crops to respond to water stress by osmotic adjustment.

After Irrigation Events

After irrigation events, the SWP was lower in the alternate furrow irrigation strategy for both crops, and across depletion levels in both years (data not shown). Again, the crops responded differently to depletion levels in each year (*Table 2*). In 2003, for some reason, green gram showed a lower SWP after irrigation events in the severe water stress depletion fraction. On the other hand, common bean showed no differences between depletion fractions, and thus had returned to a relatively high SWP. In 2004, green gram showed the highest SWP after irrigation events without differences between depletion fractions, while common bean showed a significantly lower SWP in the severe water stress treatment. In any case, it seems that both crops are able to return to a high SWP after irrigations, no matter how dry the soil was when irrigated.

Stomatal Conductance

Before Irrigation Events

In both years, common bean maintained a higher stomatal conductance than green gram across depletion fractions and furrow irrigation strategies. Stomatal conductance of both crops decreased as water stress increased, but decreased more sharply in common bean than in green gram, as shown in the crop by depletion fraction interaction (*Table 2*).

After Irrigation Events

As before irrigation events, the stomatal conductance after irrigation events of common bean was higher than green gram across depletion fractions and furrow irrigation strategies (*Table 2*). Stomatal conductance was then unaffected by depletion fractions and values for stomatal conductance were higher than the conductance before irrigation events, which seems to indicate that all plants were able to recover from the stress, although in 2003, plants in the alternate furrow strategy plots showed a lower stomatal conductance than those in the conventional every furrow irrigation plots (data not shown). This however was not significant in 2004.

Table 2. Water relations of common bean and green gram under various levels of regulated deficit irrigation and alternate furrow irrigation.

		Stem water potential (bar)				Stomatal conductance (mmol m^{-2} s^{-1})			
		Average before irrigation events		Average after irrigation events		Average before irrigation events		Average after irrigation events	
Crop	Depletion fraction	2003	2004	2003	2004	2003	2004	2003	2004
Bean	Recommended	-10.0bc*	-9.1b**	-9.2c	-8.6b	317a	449a	394a**	569a**
	Moderate stress	-11.7d	-8.8b	-8.8c	-9.0b	273b	463a	388a	544a
	Severe stress	-10.6bc	-8.6b	-9.2c	-8.7b	214c	317b	389a	520a
Green Gram	Recommended	-8.2a	-7.0a	-7.8b	-6.5a	209c	310bc	282b	406b
	Moderate stress	-8.8b	-6.7a	-106a	-6.5a	187cd	261d	372b	354c
	Severe stress	-11.2cd	-7.0a	-7.3c	-6.5a	164d	264cd	300b	338c

* Values with the same letter in the same year do not differ significantly.
** This interaction was not significant.

DISCUSSION

Our results regarding the response of common bean to water stress are consistent with the findings of other researchers, who also measured a decrease in yield. Boutraa and Sanders (2001) withheld water during the flowering and pod-filling growth stages and found that yields were reduced, and that the yield component most affected was the number of pods per plant. Dapaah *et al*. (2000) show a 50% increase in seed yield with irrigation. Nielson and Nelson (1998) have shown that seed yield was reduced due to a reduction in the number of pods per plant and the number of seeds per pod. In our experiment, however, in both years, the reduction in yield of common bean was not significant from the recommended irrigation schedule to a moderate level of stress, indicating that some level of water stress can be tolerated without significantly affecting yields.

Our yield results for green gram contrast with some of the previous experiments comparing green gram with other crops. Pandey *et al.* (1984) and Senthong and Pandey (1989) observed that green gram was quite sensitive to water stress, when compared to a series of other crops, showing the greatest decrease in yield between the well-watered control and most severe stress treatments. However, these researchers used sprinkler irrigation, and decreased irrigation water according to the distance of the experimental plot from the sprinkler. The resulting small irrigation depth may be ineffective for green gram, which, it seems, grows its roots deeper into the soil profile to extract water resources from greater depths (Haqqani and Pandey, 1994). By filling the root zone during our single irrigation event, a few days before the onset of flowering, we might well have provided green gram with sufficient water at a critical time. The same irrigation amounts applied several times in the season, a few millimeters at a time, and applied on the surface, would not have the same effect. However, Muchow (1985) found that green gram had the highest yields under water deficit conditions. In this case, the dry treatment consisted in no irrigation at all after seedling establishment. It appears thus that green gram, despite population density differences between the two years, can sustain water deficit, and might even be stimulated by it, as illustrated by the maximum yield reached in the moderate stress treatment (2003) and severe stress treatment (2004). Finally, the production approach taken by local farmers suggests that green gram is water deficit tolerant.

Because there is such diversity in the methods used to impose water stress on crops, comparisons of results among studies can be difficult. In addition, prior to the application of irrigation water, soil water deficits might be quite different among experiments, depending on the rainfall received, temperature, radiation intercepted and humidity, all factors that affect crop evapotranspiration. Unless soil moisture is monitored and serves as the basis of irrigation scheduling, the actual degree of water stress imposed might be quite variable. Given that the irrigation scheduling method utilized in this paper can be applied to all soils and all environments, we encourage researchers to work in interdisciplinary teams of plant physiologists and agricultural engineers in order to develop knowledge and technology that is useful to scientists and applicable for crop producers (see Webber et al., 2006).

Interestingly, alternate furrow irrigation, which saves 25% of the water applied by not watering every second furrow, did not significantly reduce yields, or any of the yield components measured. Although, stem water potential did show a significant decrease after irrigation events, this has not translated into yield differences. This finding is consistent with other field studies: Grimes et al. (1968) reported a 23% decrease in water use with no decrease in yields; Crabtree (1985) reported an 'acceptable tradeoff' for soybean (water use had decreased 40 to 50% while yields decreased 7 to 10%); Graterol (1993) however, showed that alternate furrow irrigation could require more irrigation events than conventional every furrow irrigation, but that net water applied was still less than the conventional every furrow irrigation, and water use efficiency was improved.

In addition, osmotic adjustment does not seem a good indicator of water stress, and considering the green gram kept a high stem water potential than common bean, it seems that it does not contribute significantly to water stress tolerance, as opposed to the findings reported in some other studies (Hsiao et al., 1984 in rice; Blum 1989, in barley; Santakumari and Berkowitz, 1990 in wheat). It seems that green gram has evolved for survival in water limited conditions as it maintains a low stomatal conductance regardless of water availability, possibly the result of a lower number of stomata on leaves. This seems related to its ability to yield better under water limited conditions than under conditions where abundant water is available, possibly by translocating more resources to seeds, as illustrated by its higher harvest index under drought. Bean on the other hand, responds (by closing stomata) to water stress once the conditions are severe enough, but, this response is too little too late, as yields are negatively affected under severe stress conditions. The lower stomatal conductance of green gram compared to common bean across depletion levels seems to indicate greater transpiration efficiency in green gram per unit of leaf area.

It appears very clear that legume production following the harvest of winter wheat is not only possible, but can also be done with relatively little water. Production of green gram using a depletion fraction of 0.80 (severe stress) and alternate furrow irrigation resulted in the highest yields with the smallest use of applied water (1,500 m^3 ha^{-1}) in 2004, when plant density was more appropriate. A similar ability to produce well under the moderate stress level (depletion fraction of 0.65 and applied water of 2,350 m^3 ha^{-1}) was also observed in 2003 (Webber et al., 2006 for water consumption). As a comparison, crops of winter wheat and cotton require averages of 4,790 and 7,070 m^3 ha^{-1} of irrigation water, respectively, under Uzbekistan conditions (SIC ICWC, 1997). The ability of green gram to yield better under conditions of water deficit is particularly demonstrated in 2004 by 36% higher yields and 40% lower water consumption for green gram in the severe stress treatment as compared to common bean in the recommended irrigation schedule. Similarly, green gram produces more leaf area and biomass than common bean under all depletion levels tested (Bourgault et al., unpublished), and with less water applied. Not surprisingly, the production of green gram under the severe stress treatment and alternate furrow irrigation showed by far the highest water use efficiency of all treatments in this experiment (Webber et al., 2006).

Further research would be necessary to assess the potential of sequential cropping of legumes instead of winter wheat or cotton, under deficit and alternate furrow irrigation. A wider range of crops should also be investigated, including cowpea, chickpea, pigeon pea, lentil, and drought-tolerant cultivars of soybean (for example, Jackson, as used in the United States, see Serraj et al., 1999), as these have shown good results under hot and dry conditions, and/or good economic viability on the world market. Development of new legume varieties, more drought tolerant, with earlier maturity, and day neutral (particularly relevant to green gram) as well as better inoculants would also be ways to improve agricultural production and food security in arid and semi-arid areas.

CONCLUSION

Our experiment shows that, under central Asian conditions, it is possible to grow a second legume crop after the harvest of winter wheat. We suggest that while both green gram and common bean are possible crops, green gram is better adapted to the conditions of Uzbekistan. A single, but deep, irrigation event might be all that is necessary for green gram to yield well, and to do so before the onset of rain and lower temperatures in the fall, given a population density high enough for the crop to reach full canopy. Our results show that deficit irrigation is also possible with bean, where yields were not substantially decreased by the moderate stress treatment. A reduction in irrigation events would also be desirable, as crop producers tend to over-irrigate to ensure even water distribution. Finally, a reduction in water use would be especially desirable if water pricing were implemented. Our experiment also showed that alternate furrow irrigation is a viable alternative to the conventional every furrow irrigation. No negative effect associated with alternate furrow irrigation was observed for yield or any of the yield components measured, nor does it seem to influence considerably water relations within the plant. Overall, deficit irrigation and alternate furrow irrigation, as well as the culture of legumes (in particular green gram) following the harvest of winter wheat could have considerable positive effects on the economy, environment and national food security of Uzbekistan and nearby areas of central Asia.

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REFERENCES

Allen, R.G., L.S. Pereira, D. Raes, M. Smith. 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. *FAO Irrigation and Drainage Paper 56*. FAO, Rome.

Blum, A. 1989. Osmotic Adjustment and Growth of Barley Genotypes under Drought Stress. *Crop Science*, 29 (1): 230-233.

Boutraa T., F.E. Sanders. 2001. Influence of Water Stress on Grain Yield and Vegetative Growth of Two Cultivars of Bean (*Phaseolus vulgaris* L.). *Journal of Agronomy and Crop Science,* 187: 251-157.

Broughton, W.J., G. Hernandez, M. Blair, S. Beebe, P. Gepts, J. Vanderleyden. 2003. Beans (*Phaseolus* spp.) - Model Food Legumes. *Plant and Soil,* 252: 55-128.

CIAT, 2001. Common Bean: The Nearly Perfect Food. http://www.ciat.cgiar.org/ciatinfocus/beans.htm Last Visited March 2005.

Crabtree, R.J, A.A. Yassin, I. Kargougou, R.W. McNew. 1985. Effects of Alternate Furrow Irrigation: Water Conservation on the Yields of Two Soybean Cultivars. *Agricultural Water Management,* 10: 253-264.

Dapaah, H.K., B.A. McKenzie, G.D. Hill, G.D. 2000. Influence of Sowing Date and Irrigation on the Growth and Yield of Pinto Beans (*Phaseolus vulgaris*) in a Sub-Humid Temperate Environment. *Journal of Agricultural Science,* 134: 33-43.

DeCosta, W.A.J.M, K.N. Shanmugathasan, K.D.S.M. Joseph. 1999. Physiology of Yield Determination of Mung Bean (*Vigna radiata* (L.) Wilczek) under Various Irrigation Regimes in the Dry and Intermediate Zones of Sri Lanka. *Field Crops Research,* 61: 1-12.

Dukhovny, V. 2005. Integrated Water Resources Management: Lessons Learned from the Aral Sea. In: Reflection On Our Future... *A New Century of Water Stewardship: Proceedings of CWRA Conference*, Banff, Canada, June 14-17, 2005.

Graterol, Y.E, D.E. Eisenhauer, R.W. Elmore. 1993. Alternate-Furrow Irrigation for Soybean Production. *Agricultural Water Management,* 24: 133-145.

Grimes D.W., V.T. Walhood, W.L. Dickens. 1968. Alternate Furrow Irrigation for San Joachin Valley Cotton. *California Agriculture,* 22: 4-6.

Hafeez, F. Y., S. Asad, K.A. Malik. 1991. The Effect of High Temperature on *Vigna radiata* Nodulation and Growth with Different Bradyrhizobial Strains. *Environmental and Experimental Botany,* 31: 285-294.
Hanelt, P., and I.P.K. Gatersleben (eds), 2001. *Mansfeld's Encyclopedia of Agricultural and Horticultural Crops. IPK Gatersleben*. http://mansfeld.ipk-gatersleben.de/Mansfeld/Taxonomy/ Last visited March 2005.
Haqqani, A.M., Pandey, R.K., 1994. Response of Mung Bean to Water Stress and Irrigation at Various Growth Stages and Plant Densities: I. Plant and Crop Growth Parameters. *Tropical Agriculture*, 71: 281-288.
Hsiao, T.C., J.C. O'Toole, E.B. Yambao, and N.C. Turner. 1984. Influence of Osmotic Adjustment on Leaf Rolling and Tissue Death in Rice (Oryza sativa L.). *Plant Physiology*, 75 (2): 338-341.
Kang, S., Z. Liang, W. Hu, J. Zhang. 1998. Water Use Efficiency of Controlled Alternate Irrigation on Root-Divided Maize Plants. *Agricultural Water Management,* 38: 69-76.
Kaplan L., and T.F. Lynch, 1999. Phaseolus (Fabaceae) in Archeology: AMS radiocarbon dates and their significance for pre-Colombian agriculture. *Economic Botany*, 53 (3): 261-272.
Micklin, P., 2000. *Managing Water in Central Asia*. Royal Institute of International Affairs, Russian and Eurasia Programme, London.
Muchow, R.C., 1985. Phenology, Seed Yield, and Water Use of Grain Legumes Grown under Different Soil Moisture Regimes in a Semi-Tropical Environment. *Field Crops Research,* 11: 81-97.
Nielson, D.C., N.O. Nelson. 1998. Black Bean Sensitivity to Water Stress at Various Growth Stages. *Crop Science,* 38: 422-427.
Pandey, R. K., W.A.T. Herrera, J.W. Pendleton. 1984. Drought Response of Grain Legumes under Irrigation Gradient: I. Yield and Yield Components. *Agronomy Journal,* 76: 549-553.
Pereira, L.S., T. Oweis, A. Zairi. 2002. Irrigation Management under Water Scarcity. *Agricultural Water Management*, 57: 175-206.
Provorov N.A., U.B. Saimnasarov, I.U. Bahromov, 1998. Effect of Rhizobia Inoculation on the Seed (herbage) Production of Mung Bean (Phaseolus aureus Roxb.) grown at Uzbekistan. *Journal of Arid Environments*, 39 (4): 569-575.
Santakumari, M., and G. Berkowitz, 1990. Correlation between the Maintenance of Photosynthesis and in Situ Protoplast Volume at Low Water Potentials in Droughted Wheat. *Plant Physiology*, 93 (3): 733-739.
Senthong C., R.K. Pandey. 1989. Response of Five Food Legume Crops to an Irrigation Gradient Imposed during Reproductive Growth. *Agronomy Journal,* 81: 680-688.
Serraj, R., T.R Sinclair, and L.C. Purcell. 1999. Symbiotic N2 fixation Response to Drought. *Journal of Experimental Botany*, 50 (331): 143-155.
SIC ICWC (Scientific Information Center of the InterState Coordination Water Commission). 1997.*Water Use and Farm Management Survey (WUFMAS).* Sub-project of WARMAP-2 (TACIS). SIC ICWC: Tashkent.
Webber, H.A, C.A. Madramootoo, M. Bourgault, M.G. Horst, G. Stulina, D.L. Smith. 2006. Water Use Efficiency of Common Bean and Green Gram Grown Using Alternate Furrow and Deficit Irrigation. *Agricultural Water Management,* 86: 259-268.